# Solar Photovoltaic Activity

<table>
<thead>
<tr>
<th>Subject Area(s)</th>
<th>number &amp; operations, physical science, science and technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associated Unit</td>
<td>Clean Energy</td>
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<tr>
<td>Associated Lesson</td>
<td>Solar Power</td>
</tr>
<tr>
<td>Activity Title</td>
<td>Solar Photovoltaic Activity</td>
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<tr>
<td>Grade Level</td>
<td>11 (9-12)</td>
</tr>
<tr>
<td>Activity Dependency</td>
<td>None</td>
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<tr>
<td>Time Required</td>
<td>30 minutes</td>
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## Summary

Students learn about the function and engineering of solar photovoltaic cells, collect, and analyze data about the photovoltaic's efficiency and power output.

## Engineering Connection

The science, engineering, and design of solar photovoltaic panels is one of the most dynamic areas of engineering research today. Students will learn the science and engineering behind the most common form of silicon photovoltaic cells while using engineering analysis principles to chose the optimum position of a photovoltaic cell relative to the sun.

## Engineering Category

Relates science concept to engineering and engineering analysis or partial design.

## Keywords

electricity, current, voltage, resistance, photovoltaic, n-type, p-type, silicon, doping, dope, solar, cell, panel

## Educational Standards

**Colorado State Science (from jesandco.net):**

- 1.5.2: Use appropriate measurements, equations and graphs to gather, analyze, and interpret data on the quantity of energy in a system or an object.
- 1.5.4: Identify different energy forms, and calculate their amounts by measuring their defining characteristics.
- 1.8.1: Gather, analyze, and interpret data to describe the different forms of energy and energy transfer.
- 1.17.2: Show that electricity in circuits requires a complete loop through which current can pass.
Colorado State Math (from jesandco.net):
• 3.16.1: Construct picture graphs and bar graphs from a data set
• 3.16.2: Read and explain information in picture graphs and bar graphs
• 4.1.3: Solve for unknown quantities in relationships involving perimeter, area, surface area, and volume

ITEEA:
• ITEEA, Standard 2, Grades 9-12, BB. Optimization is an ongoing process or methodology of designing or making a product and is dependent on criteria and constraints.

Learning Objectives
After this activity, students should be able to:
• Connect a photovoltaic panel to an external load resistor.
• Measure voltage output of a generator across a load resistor.
• Equate a photovoltaic panel's voltage output across a resistor with the panel's power output.
• Generate plots of a panel's power output vs. angle of incidence with the sun.
• Use data gathered from different solar panel angles in order to choose the most optimal panel setup.

Materials List
Each group needs:
• 1 miniature solar panel from Pitsco SunZoon car kit or similar: http://shop.pitsco.com/store/detail.aspx?ID=5921&bhcp=1
• Resistor (~330Ω will do)
To share with the entire class:
• Multimeters

Introduction / Motivation
Solar panels are wonderful, but if we do not design the panels in the correct locations and orientations, they will not be nearly as useful. In this activity, you will learn first-hand about the impact of solar panel orientation and location on panel power output.

Lesson Background & Concepts for Teachers
Solar Photovoltaic: (note: this explanation is simplified for brevity) The word "Photovoltaic" comes from the word "photo" meaning light and the word "voltaic" meaning electricity. Most photovoltaic materials available are made from silicon. Silicon is a special material because its outer-most electron shell is only half full. This shell only has 4 electrons even though it has room for 8. The silicon wants its outer electron shell to be full, so it shares its 4 electrons with 4 neighbors. Because silicon is so stable and "happy" in this structure, it does not like to give up electrons, and therefore, it does not like to conduct electricity. However, if the silicon is "doped" with an impurity such as phosphorus, it's electrical properties change. Phosphorus' outer electron shell has 5 electrons: one more than silicon. When phosphorus starts sharing electrons with silicon in the crystal, its 5th electron has nowhere "comfortable" to go. This phosphorus-doped
silicon is called n-type silicon because it has one too many electrons and is negatively charged. A similar logic applies to p-type silicon which is doped with boron which has 3 electrons in its outer shell, has too few electrons, and is positively charged. When a PN junction (meeting of n and p-type silicon) is formed, the extra electrons in the n-type silicon will move into the p-type silicon to fill up the "need" for extra electrons. If light hits the solar cell and knocks one of the electrons on the p-side loose, that electron will move from the p-side to the n-side of the sandwich. If we connect an electrical circuit from the n back to the p-side, we can use the moving electron to do work before it re-unites with the "hole" it left on the p-side.

**Angle of Incidence:** The angle of incidence of light on a solar photovoltaic panel will affect its power output. Assuming the efficiency of a panel is not affected by its angle of incidence with the sun, the power output of the panel should simply be a function of the "area" of light striking the panel. The angle θ, the angle of incidence, between a line perpendicular to the panel and the sunlight will dictate the "area" of light hitting the panel according to the following function:

\[ A_{\text{light absorbed}} = A_{\text{panel}} \cos \theta \]

Therefore, the maximum power output of the solar cell should look like a cosine curve that is a function of the angle of incidence between the light and the panel. Real-world results do not quite follow this because the diffraction coefficient of the glass that usually covers solar panels makes power falloff more dramatic at large angles of incidence.

**Calculating Power Using a Resistor:** We can calculate the power drop across a resistor as: \( P = \frac{V^2}{R} \). Therefore, if we can measure the voltage across a resistor with a multimeter, and we measure the resistance of the resistor, we can measure the power drop in the resistor. If the resistor is the only device in the circuit with the solar panel, it must be the only device that is dropping power. Therefore, the power drop in the resistor is the power production of the solar cell.
Vocabulary / Definitions

<table>
<thead>
<tr>
<th>Word</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Turbine</td>
<td>A device that converts flow energy into mechanical shaft rotation</td>
</tr>
<tr>
<td>Generator</td>
<td>A device that converts mechanical shaft rotation into electrical energy</td>
</tr>
<tr>
<td></td>
<td>(electricity)</td>
</tr>
<tr>
<td>Motor</td>
<td>A device that converts electrical energy (electricity) into mechanical</td>
</tr>
<tr>
<td></td>
<td>shaft rotation</td>
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<tr>
<td>Anemometer</td>
<td>A device that measures wind speed</td>
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<tr>
<td>Multimeter</td>
<td>A device that measures voltage, current, resistance, and any number of</td>
</tr>
<tr>
<td></td>
<td>other quantities of interest in electrical circuits</td>
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<tr>
<td>Design iteration</td>
<td>The process of continually designing, evaluating, and redesigning</td>
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<tr>
<td></td>
<td>products</td>
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<tr>
<td>Optimization</td>
<td>The process of designing a product in order to extract the most possible</td>
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<tr>
<td></td>
<td>useful results from a product</td>
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<tr>
<td>Breadboard</td>
<td>A device that allows one to connect wires without soldering</td>
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<tr>
<td>Efficiency</td>
<td>The ratio of real a real quantity to the theoretical limit of that quantity</td>
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Procedure

Before the Activity
- Find a suitable outdoor location that has both sunshine, trees (patchy shade), and solid shade.

With the Students
1. Give each student (or group) one solar panel, breadboard, resistor, and a multimeter.
2. Instruct students on how to use the handy-dandy protractor at the end of the Solar Power Skeleton Notes and Worksheets
3. Have students go out to the sunny area and complete the worksheet

Assessment

Pre-Activity Assessment:
Predictions: Ask students to form groups of 3. Students should discuss the potential power output of their solar panels. After predictions are made of power vs. angles and amounts of shade, students should draw their predictions on their worksheets.

Activity-Embedded Assessment:
Observation: The instructor should be active throughout the class during this activity. Students may struggle with how to use the protractor and will need extra help.

Post-Activity Assessment:
Redesign and Reflection: Students will be challenged to take their solar panel home, and to return it in one week. The returned solar cell should be equipped to do some useful task: power a motor, light, or anything else that is doing a useful task. This assignment will be accompanied by a one-page report on how the students chose their design need, defined constraints, brainstormed ideas, selected a final idea, prototyped and iterated on a solution.
Lesson Extension Activities
None

Additional Multimedia Support
http://science.howstuffworks.com/environmental/energy/solar-cell.htm

References
http://science.howstuffworks.com/environmental/energy/solar-cell.htm

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